Managing Sustainable Use of Land and Water under Dry Sub-humid Climate

❄❄❄❄❄❄❄❄❄❄❄[1]❄❄❄❄❄❄❄❄❄❄❄❄❄❄❄❄❄[2]

[1] *Institute of Agrometeorology, CAAS, Beijing 100081*

[2] *The Graduate School, Beijing Agriculture University, Beijing 100094*

Abstract: The majority of this study is trying to shift the theoretical consideration to the practical model and techniques in the targets of sustainable use of land and water resources under dry condition. Models of evapotranspiration, irrigation and fertilizer were adopted and developed through the data obtained from experiments in northern China. Besides that, the further study yielded managing techniques of sustainable land and water uses based on modeling results of drought mitigating and adapting strategy, irrigation timing and amount, inter-relationship between water and fertilizer, and organic manure.

Key words: Land and water resources, Sustainable uses, Dry sub-humid climate

Introduction

Land use, according to the definition of Vink (1975), “is any kind of permanent or cyclic human intervention. Land carries ecosystems. Land use is the application of human control, in a relatively systematic manner, to the key elements within the ecosystem, in order to derive benefit from it”. Land in agriculture represents soil that has fertility. Water and fertility are not only kinds of land characters, but also the key elements of the land ecosystem. Then the management of land and water in any agricultural pattern and region targets on gaining the human needs from it while controlling soil and water for lasting development of agriculture.

Dry sub-humid climate in northern China is generally defined as 500-600mm of precipitation and 1.3-1.6 of Aridity Index. In such climatic region, plant production is generally limited due to land infertility and weather aridity. A low and highly variable rainfall in temporal and spatial combines loess soil and induces drought, soil desertification, salinization, erosion and low-yield land. Agriculture here is characterized to dry-land and irrigating farming with less development of climatic potential productivity, low and variable yield, in relation to worsen environment and fragile ecosystem. Cropping system is typically described as one harvest with fallow or two crop harvests annually.

“Sustainable” means enduring and continuing, i.e., enduring and continuing of socioeconomic development, as well as resources and environment on which socioeconomic growth relies. Therefore, the sustainable development in agriculture of the region should first manage the sustainable use of land and water, i.e., “adopt the basic pattern of using and maintaining natural resources, and implement the technical change and mechanism reform to ensure the requirement of nowadays human being and their offspring to farming products. Such endurable development vindicates the resources of land, water, animal and plant genes, and is of no degradation in environment, rational application in technology, survival in economy and acceptable by the society”.

In our study area, land and water use capability is primary limited by the ecosystem and socioeconomic growth. Any successful managing technology should integrate the high output with protect and improve ecological environment, as well as be simplifying. In these cases, the study attempts to reveal the key problems in food production under dry sub-humid climate, and in turn to develop the techniques for rational use of land, water and matter resources.

Assessment of Land Productive Capability

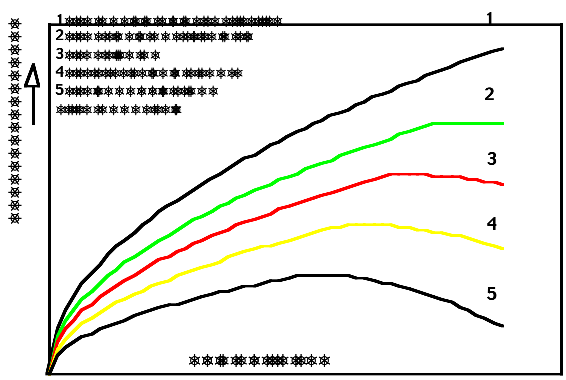
Theoretical Consideration

In agriculture, land productive capability is the comprehensive effects of natural process and human activity to agriculture, and is determined by both soil fertility and the external condition of soil. Soil fertility is defined, according to Chinese pedologists, as the function of soil water, nutrient, air and temperature. Here, the external condition involves the natural environment of climate, topography, water drainage and supply, pollution, and human practice of tillage, cultivation, etc..

Assuming that the water, nutrients, management, etc. can optically meet the crop requirement, and there exist no limiting factors to crop development, the highest land productive capability can be estimated as regional maximum potential productivity (*PP*) by AEZ method. In this condition, the land productive capability (*LPC*) is only decided by farming inputs (*X, within range of crop requirement*), and shows as:

$$LPC = P_0 + \alpha\, ?X^{\frac{1}{2}} \qquad (LPC \leq PP) \tag{1}$$

Where, P_0 is the primary land production of initial land fertility, α is a coefficient in relation to physiological features of C_3 or C_4 crop.



In fact, under natural condition, there are many factors limit to crop yield. Climate, variety, soil, water, diseases, inadequate nutrients, as well as the managing operations make different actions to reduce the yield. These factors normally work as figure 1. In general, LPC is first determined by land environment, and followed by fertility and human practice in farming. In addition, as an important element of the climate and soil environment as well as a necessary producing resource, water amount and its use efficiency mainly determine the land use pattern and land productive capability under natural arid climate. Moreover, the shortage of water influences the use efficiency of fertilizers and matters, and in turn reduce the output of land production. Therefore, LPC should be described as:

$$LPC = PP\, ?f_w\, ?f_n\, ?f_m \tag{2}$$

Where, $PP\, ?f_w$ is the climatic potential productivity (CPP) which approaches the up limit of LPC in a given region; $f_w, f_n, f_m \in [0,1]$ are functions of water supply, nutrient feeds and farming management respectively, and are given by:

$$f_w = 1 - K_y(1 - K_w) \quad or \qquad f_w = \subseteq_{i=1}^{n} (1 - K_{yi}(1 - K_{wi}))$$

$$f_n = \left(\frac{n}{N}\right)^{\frac{1}{2}} \qquad n \le N \tag{3}$$

$$f_m = F(variety,\ tillage,\ fertilizer,\ disease\ control, \ldots\ldots)$$

Where, K_y is response coefficient of crop yield to water deficit; K_w is soil moisture coefficient; i represents different crop developing stage; n, N are actual nutrient feeds and requirement of crop.

There are several methods to determine K_w. In principle, K_w is a proportion of actual crop evapotranspiration (ET_a) against crop water requirement (ET_c). In our study, K_w is calculated on the basic principles of water absorption by plant root and atmospheric extraction in relation to soil water suction (Feddes, etc.), and is statistically expressed by a simple equation associated to soil moisture directly. It is yielded as:

$$ET_a = K_w ? ET_c = K_w ? K_c ? ET_0, \qquad K_w = \frac{1}{1 + e^{A - B\frac{SM}{FC}}}$$

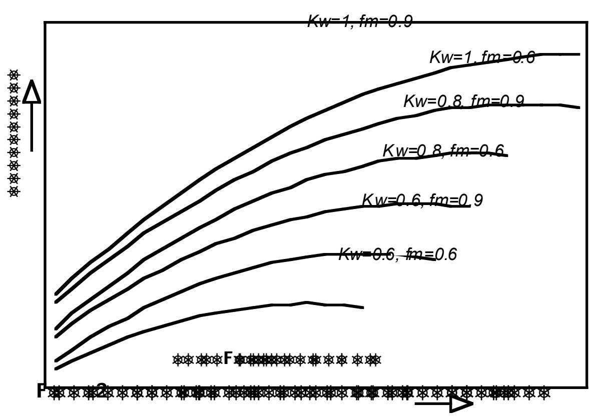
$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T + 273} U_2(e_a - e_d)}{\Delta + \gamma(1 + 0.34U_2)} \tag{4}$$

where, K_c, ET_0, SM, FC are crop coefficient, reference evapotranspiration(FAO, 1990), actual soil moisture, and field capacity; A, B are regression coefficients

Actual Land Productivity

.

Theoretically, $f_w = f_n = f_m = 1$ exists when the environment is satisfied to crop and farmland is well irrigated, fertilized and managed. In fact, under natural condition, there are many natural and social factors that influence crop yield. In these factors, water and fertility play major actions on deciding the productive capability, especially for agriculture in dry sub-humid climate. In addition, any changes of one factor will mutually influence the others, especially in the use efficiency. For example, changes of water condition will change the use efficiency of material investment of fertilizer, tillage, cultivation, etc.. It means that there exists a closely interrelation among factors of natural environment and human activities, and consequently improve or decrease the actual yield (see figure 2).



In rainfed farmland, assuming the material inputs are well managed, weeds, insects, diseases are well controlled, and the water is highly efficient used, the crop yield (Y) responds to fertilizer (X) will be written by (refer to figure 2):

$$Y = a + bX - cX^2 \tag{5}$$

Where, *a, b, c* are coefficients of greater than 0. It is obvious that there must have a maximum value at optimal input level that approaches the CPP, and can be easily derived as:

$$X = \frac{b}{2c}, \qquad Y = a + \frac{b^2}{4c} \tag{6}$$

To determine the actual land productivity, the experiment was laid out by fertility gradients and executed annually since 1988. The Randomized Complete Block design was adopted by different fertility gradient (levels), various fertilizers of manure and NPK (elements), and several replications. Data of each treatment block were converted to dimension-less units and exceed fertilizer (refer to crop requirement) block existed. Wheat and maize were selected crops that have most suitability of bio-ecology to local climate. Cultivating techniques were also well selected and supposed no limitation to crop. Furthermore, the reference baseline of climatic potential and yield response curve without limiting factors were pre-estimated by AEZ and physiological theory.

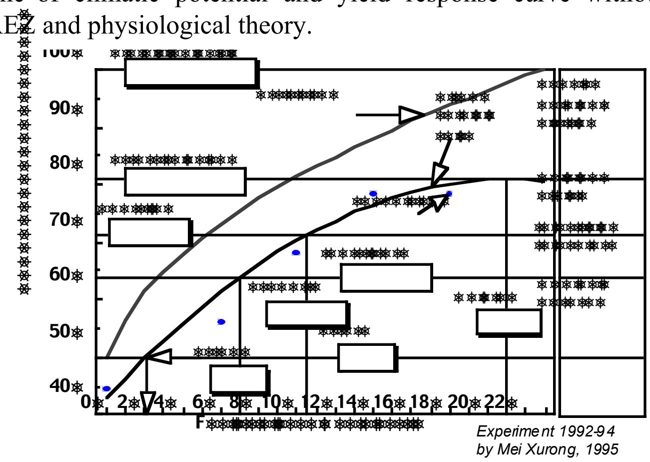


Figure 3 is derived from experi-ment during 1992-94 in Shouyang County, Shanxi Province, where trial crop of Maize is rainfed planted. In the figure, climatic potential that is estimated only with limitation of natural rainfall represents local maxi-mum LPC, the actual potential means the highest yield that can be exploited and realized when fertilizer is optimal and satisfied to crop growth, i.e. the actual land productivity (ALP). More-over, beneficial and ideal actual productivity is available yield that corresponds to investment under eco-nomic availability in experiment and inputs reality in agriculture practices respectively. The actual productivity is the yield derived from real crop production around trial site.

In comparison, we can see that the trial sample points are agreeable to simulated curve that is the same as formula (5). But there has significant difference of the maximum values between equation 6 and figure 3. The experiment result yields actual land productivity as 81% of the approached climatic potential productivity. This phenomenon asserts that there have numerous factors that are not suitable to the crop requirement.

Note that such ALP only refers the actual possibility of the yield of rainfed farmland, and does not mean the actual and economic availability. However, any farming practice exists the phenomenon of Marginal Profit Reduction. Therefore, the ALP contains implications of natural resources, environment, economy, management, their mutual promotion and restriction, and indicates the baseline of land management and sustainable agriculture.

Analysis of Limitation and Appropriate Development to Land Potential

In figure 3, there are 3 levels of crop production within the given investment: estimated production without or only with water limitation (L1), tested production with well management (L2), and actual normal production (L3). It is evident that the difference between L1 and L2 is mainly due to crop genes and land basic fertility within certain range of investment. The difference between L2 and L3 are comprehensively influenced due to several limits. All these differences are summarized into table 1.

Table 1 indicates:

(1) The maximum 19% of limitation to climatic potential comes from unsuitable varieties and inadequate land infertility, and it takes time and is difficult to improve it.

(2) Reduction of marginal profit makes 10% of production loss, and is of no avoidance.

(3) Insufficient investment in current loses 7% of the productivity and is easy to improve.

(4) It should be emphasized that the cultivating management causes 14% of the productivity. This amount of potential is mainly wasted by low use efficiency of water, fertility, that is yielded by inadequate land use pattern, cropping system, tillage, nutrients, etc.. In the experiment, the corresponding fertilizer investment to actual yield is only 2.2 units, but the actual investment has been 7 units indeed, thus the inputs use efficiency is only 30%.

[illegible] 1 [illegible]

Factors	Actions	LPC loss(%)			Ranks
		From	To	Difference	
Genetic & Fertility	Unsuitable variety, Infertility	100	81	19	1
Economy	Reduction of Marginal Profits	81	71	10	3
Investment	Insufficient matter supply	71	64	7	4
Management	Low use efficiency of inputs	64	50	14	2

Consequently, it is worthy to mention that increasing use efficiency of natural resources and farming materials by improving the managing technology is encouraged in agriculture. In addition, the figure 3 and table 1 suggest that the appropriate developing degree of land potential suggest is about 71%, which is the maximum economic availability under current farming technical level. It is evidence that the increasing inputs and favorable farming management to water and land will explore additional 21% of land potential, i.e., about 50% of production higher than current practices.

Principles and Opportunities of Managing Sustainable Land and Water Uses

The following principles are general principles that apply to the dry sub-humid climate area in China. Specific details of management that are concerned with particular schemes of technology are considered. Because priorities change from area to area, and are not meaningful to put these principles and techniques into a definite order of importance, they are therefore considered to be more or less equivalent.

Matters of Sustainable Land and Water Use

Population, resource and environment are three matters that press China's food production. In dry sub-humid climate of China, a highly variable primary production exists due to variable monsoon climate and fragile ecosystem. In addition, arable acreage reduction, population growth and water shortage appear the irreversible tendency. Such factors limit the sustainable growth of agriculture and make outstanding environment problems.

(1) Shortage, waste and over-consumption of resources exist simultaneously, land productive capability decreases. For a long term, the relative shortage of natural resources in agriculture bears food production of huge population, which induces the over-consumption of resources. Moreover, the wastes of the resources yield 30% of natural water resources and 30-40% of fertilizer use rate in

agricultural practices. This situation, combined inadequate cropping patterns, induces soil degradation of erosion and desertification that restrict the growth of agriculture in great deal, and it is significant in the study climate.

(2) Global change increases the variability of agricultural environment. Changes in climate make higher risk in agriculture to natural disasters of drought, flood, etc., and induces higher variability of agriculture and vulnerability of land ecosystem, especially in monsoon climate.

(3) The water shortage is the key elements of such process in study area. Thus, the management will finally link to water problem.

Principles of Management

(1) In request of food production, farming should target on reliable and continuing increasing arable crop yield by economizing water and fertilizer resources. In the absence of water resources, dry-land cultivation and its technology should be opportunistic to run on the most area. Other land use pattern of irrigation should remain a subsidiary form to efficient use run-off and water-harvesting resources. In both patterns, water and land conservation should be priority to be considered.

(2) In concept of sustainable development of food production, grassland, forestry are important to improve the land ecosystem and ensure the reliable food production.

(3) In order to avoid unnecessary loss of natural resources and destroy of environment in the study area, the following concepts should be mentioned in pre-decision. (a) The development of food production is rely on resources; (b) The use pattern of resources should select the economized or saving patterns; (c) Comprehensive development is the way-out of production since the environment restricts the development; (d) The fragile ecological environment requires that the development of production should be in prerequisite of harnessing; (e) Restrained by economy, nature, population and sciences, land use should follow the rule of appropriate development.

(4) According to the current situation of food production in the area, and consider the limiting factors and resources background, the selection of managing technology should be emphasized as: (a) As environment seriously influences the production, the environmental engineering is the main body of the technology; (b) In current stage, agronomic countermeasures is the major aspect of environmental engineering; (c) In view of long-term growth and environment improvement, and to recognize the soil degradation and drought events, organic agriculture should be a long-term strategy; (d) Soil fertility influences yield seriously, then chemical utilization in current therefore can not be ignored.

(5) Any managing technologies should be adopted appropriately that are not exceed the limitation of sciences and economic availability.

Technical Opportunities of Management

The following techniques show the opportunities to manage sustainable use of land and water under given area. The suitable crops to the studied climate are winter wheat, corn (*Zea Maize*), soybean and millet. All the techniques are aimed at higher productivity under dry condition and are associated with drought mitigation in such drought-prone area. Some of them are considered to be extended to most farming area of northern China.

Cropping Water Conservation -- Straw Mulching

Straw mulching was conducted in the management as improving water use efficiency (WUE) and capability of crop to drought tolerance. The experiment results are shown in table 2-5.

✽✽✽✽✽✽3✽✽✽

Cropping System	Mulching Time	Soil Evaporation (mm)		Evaporation Restraint (mm)	Restraint Rate (%)
		Mulching	Control		
W.Wheat+summer fallow	during fallow	39.7	107.9	68.2	63.2
Corn + Winter fallow	during fallow	49.8	95.0	45.2	47.6

✽✽✽✽✽✽4✽✽✽

(Winter Wheat, No. 2 Zhongmai, 1989-90, Beijing)

Treatments	Water Consumption (mm)	Evaporation		Transpiration	
		mm	%	mm	%
Mulching	301.4	113.3	37.6	188.1	62.4
Control	300.2	131.4	43.8	168.8	56.2
Difference	+1.2	-18.1	-6.2	+16.3	+6.2

✽✽✽✽✽✽5✽✽✽
✽✽✽✽✽✽

Year	Crops	Rainfall (mm)	Evapotranspiration (mm)		Yield (kg ha^{-1})		WUE (kg mm^{-1} ha^{-1})	
			Mulching	Control	Mulching	Control	Mulching	Control
1988/89	winter wheat	264.7	376.3	378.9	5332.5	4206.0	14.17	11.10
1989/90	winter wheat	219.0	353.0	361.3	4800.0	4000.0	13.60	11.07
1988	Corn	532.0	340.1	338.4	7945.5	5025.0	23.36	14.85
1989	Corn	413.0	401.8	396.4	10648.5	8640.0	26.50	21.80

Numerous results in different regions agree that straw mulching significantly improves the field ability of natural rainfall uptake, soil water supplying, and soil evaporation restricting. To recognizing the water and fertility shortage in the study area, these actions of straw mulching are important to economize the limited water resources, as well as avoid over uptake of soil nutrients. It is also emphasized that straw mulching makes no change of crop gross water consumption against control one, but it changes the portion between soil evaporation and plant transpiration. This is meant of straw mulching improving use efficiency of limited water resources, and in turn improving crop productivity.

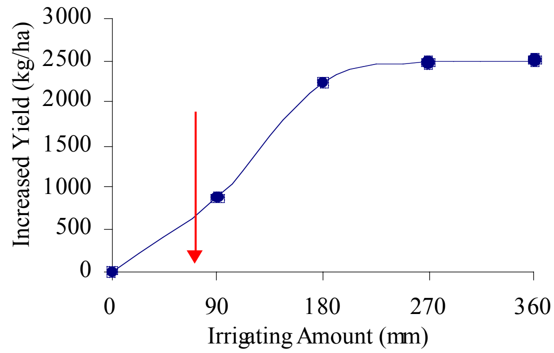
✽✽✽✽✽✽2✽✽✽

Treatments	Winter Wheat Field*			Corn Field**		
Parameters	Mulching	Control	Difference	Mulching	Control	Difference
Precipitation	264.7	264.7	0.0	413.0	413.0	0.0
Evapotranspiration	376.3	378.9	-2.6	401.8	396.4	+5.4
Soil Rainfall Storage	153.4	105.6	+47.8	207.0	137.7	+69.3
Soil Water Supply	261.3	237.2	+24.1	232.7	199.8	+32.9

* Mulch in growth period, 11/01/88-06/25/89 of 09/20/88 -- 06/25/89, in Tunliu county, Shanxi province

** Mulch in growth period, 05/25/89-09/20/89 of 04/25/89 -- 09/20/89, in Tunliu county, Shanxi province

Notes that the low use efficiency of water and fertilizer conducted 14% loss of ALP, straw mulching is the useful technology to mitigate the impacts of dry condition on crop production. To avoiding the side-effects of straw mulching, the suitable region of the technology should the area where annual mean temperature is higher than 8 degree Celsius.



Winter wheat, 1987/88, Tunliu, P=159.0mm, ETc=513.0mm, ETa(non irri.)=320.1mm

F[illegible]4[illegible]

Insufficient Irrigation (Supplementary Irrigation)

Insufficient irrigation is one kind of supplementary irrigation that watering crop without satisfying its water requirement. It is a meaningful method in the water shortage area. There are two basic principles to be considered in the technique, one is that the crop has the tolerant ability to water shortage without productivity loss, the other is that supplying crop water as its requirement is not worthwhile in economy. Therefore, the insufficient irrigation experiment (RCB, 4 irrigation timing * 4 irrigation amount) was conducted, and then the insufficient irrigation was scheduled by equation 4 and trial results in figure 4.

In view of crop water requirement and drought tolerance, and in consideration of optimal yield, the *lower threshold value* of insufficient irrigation can be derived from the equation (4), i.e.,:

$$\frac{f^2 K_w}{f\theta^2} = 0, \qquad \frac{SM}{FC} = \frac{A}{B} \tag{7}$$

In our study, such threshold value of winter wheat in Tunliu county of Shanxi province is 0.55, i.e., when the relative soil moisture decrease to 55%, the crop water consumption is about 50% of its requirement, the irrigation should be considered.

The *upper threshold value* of insufficient irrigation can be defined as the watering peak-point of marginal yield (see figure 7). At the peak-point, irrigation amount is about 135mm of water, thus the gross actual water consumption yields as 455.1mm (=135mm +320.1mm), that is of 88.7% of crop water requirement. Therefore, the upper threshold value is calculated by equation (4) as 0.82 of relative soil moisture.

In general, since there exists a water shortage to crop requirement and possible water resources for watering crop, it is suggested to economically control soil relative moisture within 0.55-0.82 by irrigation, that is, supplies crop water by 50-90% of its water requirement.

Cropping Rotation and Intercropping

Cropping rotation and intercropping are the main contents of cultivation system. In the study, such techniques are shifted to economizing water uses of improving water use rate and use efficiency, and ensuring stable annual production. In difference, cropping rotation in Chengcheng County, Shan'xi province focuses on fully using natural rainfall, while the intercropping in Shouyang county of Shanxi province is mainly designed to use water efficiently. Table 6,7,8 show the results.

6 [1]

Treatments	Rotate Pattern*	Rainfall** (mm)	Water Usage** (mm)	Yield (kg ha^{-1})**	Water Use Rate**(%)
4 mature 3 year	W-W+M-P	1564.4	1200.3	11901.0	76.7
Control	W-W-W	1564.4	795.3	9424.5	50.8
Difference	--	0.0	+405.0	+2476.5	15.9

*: W=winter wheat, M=millet, P=pea; '-' =between year; '+' =within 1 year. **: gross amount of whole rotation cycle.

7

Year	Cropping*	Corn		Soybean		Gross yield kg ha^{-1}	Coefficiency
		Yield kg	Area rate	Yield kg	Area rate		
1993	type 1	2832.0	1/3	1210.5	2/3	4042.5	1.362
	mono-	5496.0		1705.5		2968.5	-
	type 2	3861.0	1/2	979.5	1/2	4840.5	1.342
	mono-	5496.0		1705.5		3601.5	-
1994	type 2	5826.0	1/2	915.0	1/2	6741.0	1.397
	mono-	7674.0		1975.5		4825.8	-

* Intercropping type: 1 = 3 rows of corn + 6 rows of soybean; 2 = 3 rows of corn + 3 rows of soybean; mono- = single cropping of corn and soybean respectively.

8

Year	Cropping type	Area portion corn:soybean	Intercropping ETa (mm)	Single-cropping ETa (mm)			Coefficiency
				Corn	Soybean	Refer-ETa*	
1993	Intercropping 1	1:2	375.5	407.5	360.3	376.0	0.999
	Intercropping 2	1:1	380.4			383.9	0.991
1994	Intercropping 2	1:1	411.3	434.4	381.6	408.0	1.008

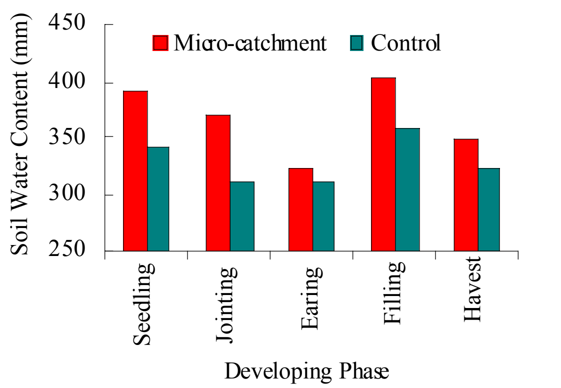
* Convert single cropping ETa to intercropping refer to area portion of two crops

The observed results indicate: (1) Cropping rotation makes multiple cropping available, and then induces fully use of natural precipitation; (2) Intercropping between corn and soybean does not change the field water consumption in contrast to single cropping; (3) Both of them can yield higher production, but in the mechanism, cropping rotation uses more water to induce additional production, while intercropping uses limited water more efficiently for extra-grain harvest.

Water Harvesting -- Micro-catchment

[1] Rotation Cycle: Sept. 1986 - Sept. 1989, in Chengcheng county, Shan'xi province

Water harvesting is described as collecting and storing natural rainfall, farmland, water cellar and reservoir are the water harvesting destination. There are successful practices of water harvesting, such as contour planting, terrace. The micro-catchment is one kind of the water harvesting, but it focuses on field scale and root zone. It is defined in this study as creating runoff by ridges in a flat farmland to concentrate rainfall into planting area and root zone. The high-water-absorbed substance is also used to catch and collect soil water surrounding plant root and providing crop proper growing condition of water. Followed the design, an experiment was laid out during 1992-94 in Shouyang county, Shanxi province. In the experiment, the ridges were covered by plastic film, fertilizer was used in the gullies between ridges, and crop of corn was planted in the furrows.



F[illegible]5[illegible]2[illegible]

Figure 5 presents the effects of ridged micro-catchment on soil moisture content in 2m soil layer. It is obviously seen from the figure that the soil moisture content of ridged field is higher than that of flat field in each growing stage. Studies of temporal dynamics of soil moisture illustrate that, in contrast, the micro-catchment collected more rainfall for infiltrating to soil, and conserved more water from evaporation. This additional amount of water from rainfall and evaporation benefits corn growth and consequently improves water use efficiency. Table 9 shows us the effect of micro-catchment on corn yield and WUE. It should be pointed out that the crop in micro-catchment field does not consume more water than that of controlled farmland. Therefore, it can be concluded that a powerful water cycle exists in the field. This asserts that micro-catchment by ridges should be a useful means for water resource management of farming in the dry sub-humid climate.

Interaction between Water and Fertilizer to Crop Production

Many studies of interaction between fertilizer and water on crop yield have been conducted. Results have been seemed different from area to area and crop to crop. To capture the common features and get grid of individual characteristics of the relationships between water and fertilizer, the conclusion of it can be statistically summarized as: (1) Under certain water condition of a given area, crop yield responds to fertilizer input with a simplifying parabola curve, but crop water consumption has no significant difference. (2) Under certain fertilizer supply, crop yield responds to increasing water usage with S-curve. (3) In rainfed farmland within study climate, the water use efficiency of crops is sensitive to changes of fertilizer, but is no significant response to water supply. In other word, the coefficient of crop water consumption is steady unless fertility changed. (4) Increment of

[illegible]9[illegible]

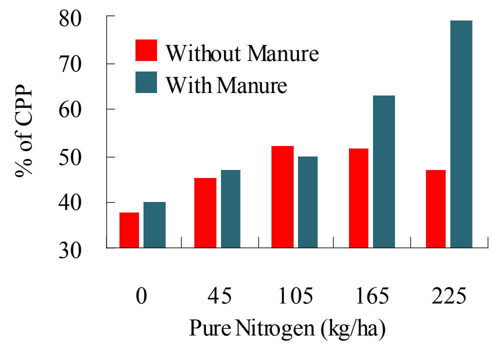
Year	Treatment	Yield		Evapotranspiration		WUE	
		kg ha^{-1}	±	mm	±	kg m^{-3}	±
1992	Micro-catch	7294.5	+2716.5	391.6	-23.7	1.860	+0.765
	Control	4578.0	--	415.3	--	1.095	--
1993	Micro-catch	6939.0	+1443.0	374.6	-32.9	1.845	+0.495
	Control	5496.0	--	407.5	--	1.350	--
1994	Micro-catch	9834.0	+2160.0	473.2	+33.9	2.085	+0.315
	Control	7674.0	--	434.3	--	1.770	--

water supply will increase crop yield in any fertilizer grade, but higher fertilizer usage only has significant influence on yield at higher level of water supply.

Under the water shortage condition in this study area, the foregoing results may conclude the water management is encouraged prior to fertilizer. That means, in such agricultural condition, the fertilizer is determined by water condition, and is used to adjust water condition

Utilization of Organic Matter (Manure) -- Improving Water and Fertilizer Efficiency

Organic matter (manure) has been reported more in its major farming feature of improving soil structure and land fertility, and then increasing rainfall infiltration, controlling evaporation, as well as conserving soil moisture, etc.. It is true and useful in our study area. Using organic matters in dryland farming targets on sustainable use of land and water resources. Furthermore, the manure use will help us to improving the use efficiency of water and land. Thus, the experiments had been carried out to crops since 1987, and the effects on water and fertilizer use efficiency were analyzed in detail.



F[illegible]6[illegible]

Figure 6 shows the experimental results in Tunliu county of Shanxi province during 1988-1990. The portion of Climate Potential Productivity is used to convert dimension-less crop yield, which is the comparable data of different experiment years. It is evident from the figure that the reduction of yield against high grade of fertilizer input exists in the field without manure. On the contrary, the yield of manure farmland continuous increases within trial fertilizer grade. Should we assert that such difference is due to not only the action of manure itself, but also the action of manure increasing the fertilizer use efficiency?!

The another feature of manure from experiment is the significant influence on improving water use efficiency. Noting that our study farming is restricted by both water shortage (aridity) and land infertility, the organic matter should be emphasized as a long-term strategy for sustainable use of land and water, and a useful means of land and water management.

Discussion

To managing sustainable land and water use appropriately, it should be emphasized: (1) The resource shortage will exist continuously and is seemed irreversible, therefore the fully use of natural resources should be the long-term strategy; (2) As socioeconomic development and the growth of agricultural products requirement, the high pressure of arable land will be still constant, the growth of higher production should be prior to others; (3) The management should concentrate to mitigate the socioeconomic contradictions of population and arable land, economic growth and resource protection, and technical contradiction of high yield and economic availability, insufficient resources and low use efficiency, aridity and infertility, extensive and intensive cultivation, etc..

In general, the managing sustainable land and water use is a systematic operation for actual farming practices. It may involve to pre-decide appropriate development to potential productivity of natural resources, to adapt and optimal use agronomic technologies of cropping and tillage system, to explore environmental engineering and high technology to equip the agriculture, etc.. However, to recognize the current situation of dryland farming and its future in dry sub-humid climate, the successful managing technology of water and land should first never ignore the ordinary cultivation to improve material use efficiency since it makes 14% loss of actual potential productivity. The second step is suggested to increase the invest gradually for constant growth of agriculture. In the view of further development of agriculture, the high-tech environmental engineering in agriculture (water harvesting, economized irrigation-fertilizer, evaporation controlling, industrialized agriculture, etc.) will contribute to enduring growth of agriculture. Finally, varieties of drought tolerance and higher productivity will give agriculture availability to explore the natural potential.

References

1. C. T. de Wit, Physiological Potential of Crop Production, In: *J. Sneep, et al.(Eds.), Plant Breeding Prospective*, Pudoc, Wageningen, 1979, 47-81
2. Daniel Hillel, Application of Soil Physics, *Academic Press*, New York, 1980
3. FAO, Efficient Fertilizer Use in Summer Rainfed Areas, *Fertilizer and Plant Nutrition Bulletin 11*, Rome, 1988
4. H. M. Taylor, et al, Limitation to Efficient Water Use in Crop Production, *American Society of Agronomy, American Society of Crop Sciences & American Society of Soil Sciences*, Madison, 1983
5. J. Doorenbos, A.H. Kassam, Yield Response to Water, *FAO, Irrigation and Drainage Paper*, 33, 1979
6. Lu Liangshu, Development of Agriculture and Achievement of Science and Technology in China, *Shandong Science and Technology Press*, Jinan, 1992 (in Chinese)
7. Mei Xurong, et al, The Supplying and Requiring Features of Dry Farmland Moisture in Tunliu County and Effect Analysis of Straw Mulching, *Chinese Agricultural Meteorology*, Vol 12(1), 1990 (in Chinese)
8. N. C. Turnen, P. J. Karmer, Adaptation of Plants to Water and High Temperature Stress, *John Wiley & Sons, Inc. Press*, 1980
9. P. J. Karmer, Water Relations of Plants, *Academic Press*, New York, 1983
10. R. S. Loomis, P. A. Gerakis, Productivity of Agricultural Ecosystems, *Photosynthesis & Productivity in Different Environments*, 1975, 145-172
11. Tao Yufen, et al, Water Potential Productivity and Its Development in Dryland Farming Region of Northern China, *China Meteorological Press*, 1992 (in Chinese)
12. Wang Hongguang, China Agriculture: Problem, Potential, Path and Benefit, *Agriculture Press*, Beijing, 1993 (in Chinese)
13. Zhao Jubao, Mei Xurong, Effect of Straw Mulching on Water-economizing and Yield-increment, in *Water-Saving Technology in Agriculture, Water Conservancy and Electric Power Press*, 1992 (in Chinese)